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The Design and Manufacturing of Machine Tapered Shaft Measuring Tool

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***Abstract*—Machine tapered shaft is a shaft with a difference between left and right diameter, and any difference of diameter will cause the formation of taper. To limit the number of tapering that occurs, many taper standards such as ISO, Morse Taper, and others are created. As an example, a workpiece of Morse Taper 03 standard has a taper angle of 1.47778 degree. Until now there is no measuring instrument that could measure the precision taper angle directly. To fill this unavailability is need to design an equipment to measure precision tapered shaft easily that requires only a set of dial indicator unit in 0,001 mm accuracy and the block which designed to shift along the guide way. The results of the measurement tests carried out are able to measure with a deviation of only 0.003 mm for a measurement length of 250 mm, or just 0 degree 0 minute 2.5 second. Overall, the objective of this research can be achieved by realization a set of tapered precision workpiece measuring equipment quite simple and easy to operate because it only use the indicator dial and its seat block which has been modified for the needs of precision tapered workpiece measurement.**

Keywords—taper, precision, measurement, practice, dial indicator

I. Introduction

A machine taper shaft is a system for securing cutting tools or toolholders in the spindle of a machine tool or power tool. A male member of conical form (that is, with a taper) fits into the female socket, which has a matching taper of equal angle.

Almost all machine tool spindles, and many power tool spindles, have a taper as their primary method of attachment for tools. Even on many drill presses, handheld drills, and lathes, which have chucks (such as a drill chuck or collet chuck), the chuck is attached by a taper. On drills, drill presses, and milling machines, the male member is the tool shank or toolholder shank, and the female socket is integral with the spindle. On lathes, the male may belong to the tool or to the spindle; spindle noses may have male tapers, female tapers, or both [1]. Drill chucks, drill bits, and reamer having tapered shafts with a certain taper standard can be seen in Figure 1.

Fig. 1. Drill chucks, drill bits, and reamer having tapered shafts with a certain taper standard.

Machine tool operators must be able to install or remove tool bits quickly and easily. A lathe, for example, has a rotating spindle in its headstock, to which one may want to mount a spur drive or work in a collet. Another example is a drill press, to which an operator may want to mount a bit directly, or using a drill chuck. The machine taper is a simple, low-cost, highly repeatable, and versatile tool mounting system. It provides indexability, as tools can be quickly changed but are precisely located both concentrically and axially by the taper. It also allows high power transmission across the interface, which is needed for milling. Machine tapers can be grouped into self-holding and self-releasing classes. With self-holding tapers, the male and female wedge together and bind to each other to the extent that the forces of drilling can be resisted without a drawbar, and the tool will stay in the spindle when idle. It is driven out with a wedge when a tool change is needed. Morse and Jacobs tapers are an example of the self-holding variety. With self-releasing tapers, the male will not stick in the female without a drawbar holding it there. However, with good drawbar force, it is very solidly immobile. NMTB/CAT, BT and HSK are examples of the self-releasing variety [2].

For light loads (such as encountered by a lathe tailstock or a drill press), tools with self-holding tapers are simply slipped onto or into the spindle; the pressure of the spindle against the workpiece drives the tapered shank tightly into the tapered hole. The friction across the entire surface area of the interface provides a large amount of torque transmission, so that splines or keys are not required. For use with heavy loads (such as encountered by a milling machine spindle), there is usually a key to prevent rotation and/or a threaded section, which is engaged by a drawbar that engages either the threads or the head of a pull stud that is screwed into them. The drawbar is then tightened, drawing the shank firmly into the spindle. The draw-bar is important on milling machines as the transverse force component would otherwise cause the tool to wobble out of the taper [3].

The machine taper shaft quiet easy to made in the machine shop if equipted from medium to high carbon steel, if the shop is equipted with turning and cylindrical grinding machine. The difficulty is how to measure the shaft taper angle precisely, because untill today there is still no apparatus for measuring taper shafts directly and easily. There are two different methods to measure the machine tapered shaft, the first is directly measure the larger diameter (Ø D) and the smaller diameter (Ø d) of the shaft and then measure the distance between those diameter (see Figure 2).

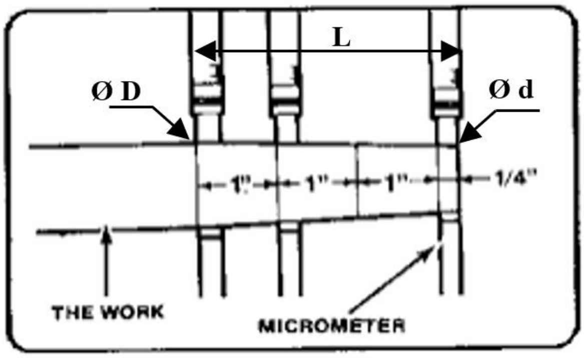

Fig. 2. Schematic drawing of tapered workpiece measurement using a micrometer.

The measurement results of Ø D and Ø d are then used to determine the angle of inclination of the workpiece by using the equation (1) is used to calculate the value of tapered workpiece [2].

$$\alpha = \left(\frac{\emptyset D - \emptyset d}{2 \times L}\right) \quad (1)$$

α = The angle of inclination of the workpiece

ØD = Diameter of the large side of the workpiece

Ød = Diameter of the small side of the workpiece

L = Distance between ØD and Ød

To find out the calculation results from the above equation, one unit of scientific calculator is needed which is able to provide calculation results down to the second (") number.

The second method usually use to measure the tapered shaft are using a series of measuring equipment to use as a unit of machine tapered shaft measuring tool (see Figure 3).

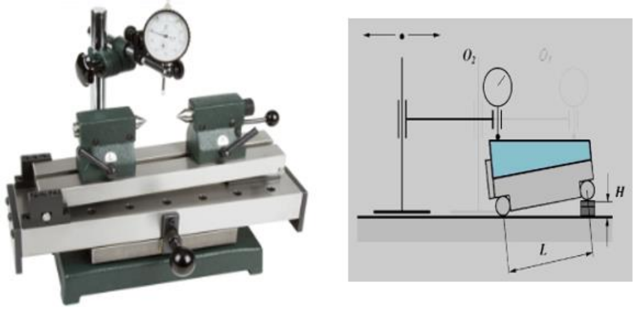

Fig. 3. Measuring the machine tapered shaft by using a set of sinus table, dial indicator set, and gage block set.

In order to make measuring the taper angle of the machine tapered shaft become easier, it is necessary to design and manufacture a set of precision taper shaft's angle measuring device [4].

A. Objectives

- Developed the method of measuring the precision tapered workpiece directly.
- Design and realize a prototype of a precision tapered workpiece measuring device in person that is easy to manufacture and inexpensive because there is no need to use very expensive measuring tool (e.g. gage block set grade " 00") and special clamping tool (e.g. sine vice).
- To review the equipment's performance and deviation in measuring capability.
- Introducing the method of measuring precision tapered workpieces directly to the public who use angle measuring instruments.

II. Methods

A. Experiment's Material

The material used in this experiment is S35C steel which has a maximum carbon content up to 0.35% with an average tensile strength of 500 N / mm2 and a surface hardness of 79 HR_B [5].

B. Research Equipment

Research equipment used in this experiment is placed in Machining Laboratory and Material Testing Laboratory at Politeknik Negeri Semarang.

C. The Experimental Variables

The variables carried out in this study are the inclination of the tapered workpiece and the length of dial indicator block movement. All of these variables will affect the results of tapered workpiece measurement.

D. The Experimental Steps

The experimental steps carried out in this study are as follows:

- Prepare a design of the precision taper workpiece measuring device (see Figure 4).
- Realized the design precisely and install all the equipment on the device.
- Prepare the specimens of precision taper workpiece according to targets that have been set.
- Install the specimen test object between the two center that have been aligned
- Turn on the dial indicator.
- Adjust the position of the indicator dial according to the diameter of the specimen, and touch the stylus end of the indicator dial to the specimen surface
- Slide the indicator dial block along the surface of the specimen where the tapered workpiece is to be measured
- Read the inclination measurement result on the indicator dial screen.
- Read the shift distance dial indicator block
- See the measurement results in the taper angle table based on the inclination value versus the shift length.
- The value of the degree of taper angle of the workpiece will be found in the table completely (° ' ").

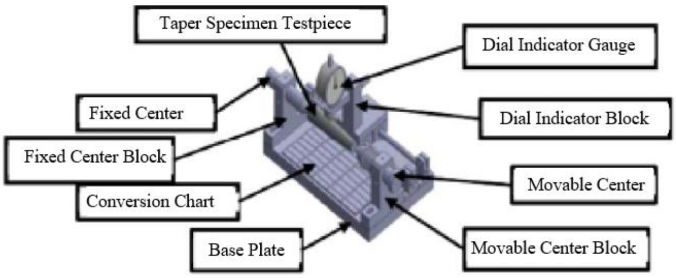

Fig. 4. Design of precision tapered workpiece measuring device.

E. Research Output

The output of this research is a prototype of a Precision Taper Workpiece Measuring Device which can be used by mechanical engineering student.

F. Outcome Indicator

The expected outcome indicator expected of this research is the ability of the device to measure the precision taper angle of the workpiece accurately, at least the deviation that occurs no more than 5 seconds [6].

III. RESULTS AND DISCUSSION

A. Results

The result of design realization of precision tapered workpiece measuring tool is a unit of a device as shown below (Figures 5- 8).

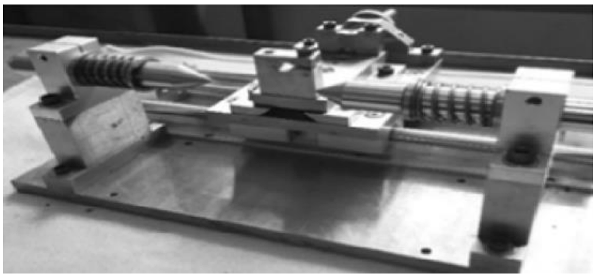

Fig. 5. Precision tapered workpieces measuring tool unit.

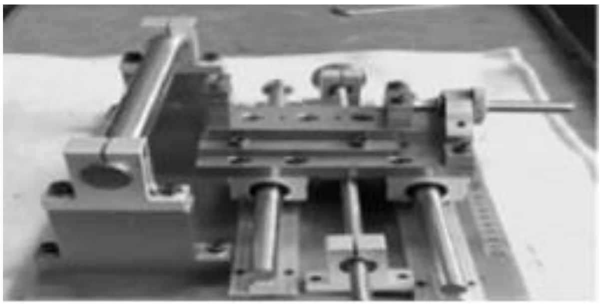

Fig. 6. Precision Tapered Workpieces Toll Unit being calibrate for the straightness of the center block.

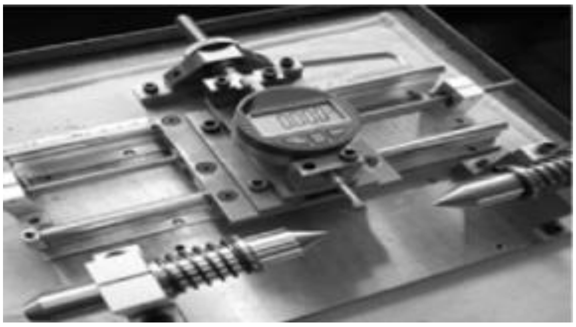

Fig. 7. Precision tapered workpiece measuring tool unit being calibrate for center alignment.

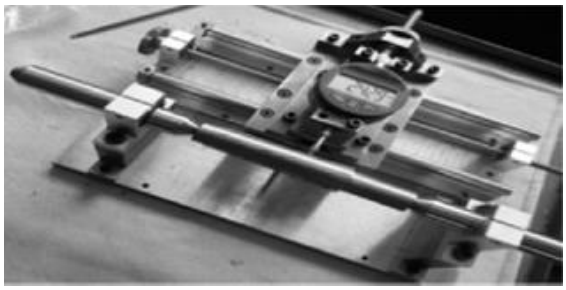

Fig. 8. Precision tapered workpiece measuring tool unit being calibrate for tapered specimen.

In carrying out the performance test of the precision workpiece taper measuring equipment unit, several workpieces with standard tapers and measuring tools is used as follows :

- Workpieces with standard taper, including Morse Taper 03 Taper Shank, ISO 30 Taper Shank, ISO 40 Taper Shank (see Figures 9 and 10).
- Vernier caliper with 0.02 mm accuracy to measure the length of the shift of the dial indicator block.
- Digital dial indicator with an accuracy of 0.001 mm and a stylus measuring range of 12.7 mm.
- By using of the prototype of the Precision Tapered Workpiece Measuring Tool can be used more practically.
    - The results of taper measurement are obtained by calculating using **the eq. (1)** are calculated as follow, for example, if the inclination result on the dial indicator display is 0.250 mm and the shift of dial indicator block is 100 mm. It means the tapered angle of the workpiece is 0° 8' 36".
- Such measurements are carried out repeatedly with different variables, and the results of the calculations are tabulated (see Figure 11).

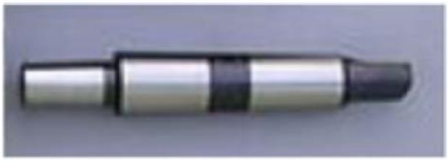

Fig. 9. MT 03 drill chuck handle [7].

Fig. 10. ISO 40 drill chuck handle [7].

Reading on the dial indicator display (mm)	Dial indicator block shift (mm)									
	10	20	30	40	50	60	70	80	90	100
0.005	0° 1' 43"	0° 0' 52"	0° 0' 34"	0° 0' 26"	0° 0' 21"	0° 0' 17"	0° 0' 15"	0° 0' 13"	0° 0' 11"	0° 0' 10"
0.010	0° 3' 26"	0° 1' 43"	0° 1' 9"	0° 0' 52"	0° 0' 41"	0° 0' 34"	0° 0' 30"	0° 0' 26"	0° 0' 23"	0° 0' 21"
0.015	0° 5' 9"	0° 2' 35"	0° 1' 43"	0° 1' 17"	0° 1' 2"	0° 0' 52"	0° 0' 44"	0° 0' 39"	0° 0' 34"	0° 0' 31"
0.020	0° 6' 52"	0° 3' 26"	0° 2' 18"	0° 1' 43"	0° 1' 23"	0° 1' 9"	0° 0' 59"	0° 0' 52"	0° 0' 46"	0° 0' 41"
0.025	0° 8' 36"	0° 4' 8"	0° 2' 52"	0° 2' 9"	0° 1' 43"	0° 1' 26"	0° 1' 14"	0° 1' 4"	0° 1' 4"	0° 0' 52"
..	......	......	......	......	......	......	......	......	......	......
..	......	......	......	......	......	......	......	......	......	......
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0.150	0° 51' 34"	0° 25' 47"	0° 17' 11"	0°12' 53"	0°10' 19"	0° 8' 36"	0° 7' 22"	0° 6' 27"	0° 5' 44"	0° 5' 9"
0.155	0° 53' 17"	0° 26' 39"	0° 17' 46"	0°13' 19"	0°10' 39"	0° 8' 53"	0° 7' 37"	0° 6' 40"	0° 5' 55"	0° 5' 20"
0.160	0° 55' 0.2"	0° 27' 30"	0° 18' 20"	0°13' 45"	0° 11' 0"	0° 9' 10"	0° 7' 52"	0° 6' 53"	0° 6' 7"	0° 5' 30"
0.165	0° 56' 43"	0° 28' 22"	0° 18' 54"	0°14' 11"	0° 11' 21"	0° 9' 27"	0° 8' 6"	0° 7' 5"	0° 6' 18"	0° 5' 40"
0.170	0° 58' 27"	0° 29' 13"	0° 19' 29"	0°14' 37"	0°11' 41"	0° 9' 44"	0° 8' 21"	0° 7' 18"	0° 6' 30"	0° 5' 50"
0.175	1° 0' 10"	0° 30' 5"	0° 20' 3"	0° 15' 2"	0° 12' 2"	0° 10' 2"	0° 8' 36"	0° 7' 31"	0° 6' 41"	0° 6' 1"
0.180	1° 1' 53"	0° 30' 56"	0° 20' 38"	0° 15' 28"	0° 12' 23"	0° 10' 19"	0° 8' 50"	0° 7' 44"	0° 6' 53"	0° 6' 11"
0.185	1° 3' 36"	0° 31' 48"	0° 21' 12"	0° 15' 54"	0° 12' 43"	0° 10' 36"	0° 9' 5"	0° 7' 57"	0° 7' 4"	0° 6' 22"
0.190	1° 5' 19"	0° 32' 40"	0° 21' 46"	0° 16' 20"	0° 13' 4"	0° 10' 53"	0° 9' 20"	0° 8' 10"	0° 7' 15"	0° 6' 32"
0.195	1° 7' 2"	0° 33' 31"	0° 22' 21"	0° 16' 46"	0° 13' 24"	0° 11' 10"	0° 9' 35"	0° 8' 23"	0° 7' 27"	0° 6' 42"
0.200	1° 8' 45"	0° 34' 23"	0° 22' 55"	0° 17' 11"	0° 13' 45"	0° 11' 28"	0° 9' 49"	0° 8' 36"	0° 7' 38"	0° 6' 53"
0.250	1° 25' 57"	0° 42' 58"	0° 28' 39"	0° 21' 29"	0° 21' 29"	0° 14' 19"	0° 12' 17"	0° 10' 45"	0° 9' 33"	0° 8' 36"
0.500	2° 51' 53"	1° 25' 57"	0° 57' 18"	0° 42' 58"	0° 34' 23"	0° 28' 39"	0° 24' 33"	0° 24' 33"	0° 19' 6"	0° 17' 11"
0.750	4° 17' 50"	2° 8' 55"	1° 25' 57"	1° 4' 27"	0° 51' 34"	0° 42' 58"	0° 36' 50"	0° 32' 14"	0° 28' 39"	0° 25' 47"
1.000	5° 43' 46"	2° 51' 53"	1° 54' 35"	1° 25' 57"	1° 8' 45"	0° 57' 18"	1° 25' 57"	0° 42'58"	0° 38' 12"	0° 34' 23"
1.250	7° 9' 43"	3° 34' 52"	2° 23' 14"	1°47'26"	1° 25' 57"	1° 11' 37"	1° 1' 23"	0°53' 43"	0° 47' 45"	0° 42' 58"
1.500	8° 35' 40"	4° 17' 50"	2° 51' 53"	2° 8' 55"	1° 43' 8"	1° 25' 57"	1° 13' 40"	1° 4' 27"	0° 57' 18"	0° 51' 34"
1.750	10° 1' 36"	5° 0' 48"	3° 20' 32"	2° 30' 24"	2° 0' 19"	1° 40' 16"	1° 25' 57"	1°15' 12"	1° 6' 51"	1° 0' 10"
2.000	11° 27' 33"	5° 43' 46"	3° 49' 11"	2° 51' 53"	2° 17' 31"	1° 54' 35"	1° 38' 13"	1°25' 57"	1° 16' 24"	1° 8' 45"
2.250	12° 53' 30"	6° 26' 45"	4° 17' 50"	3° 13' 22"	2° 34' 42"	2° 8' 55"	1° 50' 30"	1° 36' 41"	1° 25' 57"	1° 17' 21"
2.500	14° 19' 26"	7° 9' 43"	4° 46' 29"	3° 34' 52"	2° 51' 53"	2° 23' 14"	2° 2' 47"	1°47' 26"	1° 35' 30"	1° 25' 57"
2.750	15° 45' 23"	7° 52' 41"	5° 15' 8"	3° 56' 21"	3° 9' 5"	2° 37' 34"	2° 15' 3"	1°58' 10"	1° 45' 2"	1° 34' 32"
3.000	17° 11' 19"	8° 35' 40"	5° 43' 46"	4° 17' 50"	3° 26' 16"	2° 51' 53"	2° 27' 20"	2° 8' 55"	1° 54' 35"	1° 43' 8"
3.250	18° 37' 16"	9° 18' 38"	6° 12' 25"	4° 39' 19"	3° 43' 27"	3° 6' 13"	2° 39' 37"	2°19' 40"	2° 4' 8.45"	1° 51' 44"
3.500	20° 3' 13"	10° 1' 36"	6° 41' 4"	5° 0' 48"	4° 0' 39"	3° 20' 32"	2° 51' 53"	2°30' 24"	2° 13' 41"	2° 0' 19"
3.750	21° 29' 10"	10°44' 35"	7° 9' 43"	5° 22' 17"	4° 17' 50"	3° 34' 52"	3° 4' 10"	2° 41' 9"	2° 23' 14"	2° 23' 14"
4.000	22° 55' 6"	11°27' 33"	7° 38' 22"	5° 43' 46"	4° 35' 1"	3° 49' 11"	3° 16' 27"	2°51' 53"	2° 32' 47"	2° 17' 31"

Fig. 11. Angle to tapered inclination conversion table.

B. Discussion

It is necessary to measure the workpiece repeatedly with different angles in order to know how much deviation from the measurement results. The deviation of the size results that occurs an average of 0.004 mm, this happens because the smoothness of the grinding surface of the cylinder is N7 ~ N6 or the Roughness average (Ra) value is 1.6 ~ 0.8 μm [8]. Ra level of this magnitude can still be detected by the stylus dial indicator with an accuracy level of 1 μm. So that in order to indicate the size by the dial indicator to be more optimal, the surface of the test object must receive further surface treatment in the form of a lapping process or an honning process [9].

IV. Conclusion

The method of measuring the precision tapered workpiece directly can be done by using this competitive applied research measurement tool.

- A set of precision tapered workpiece measuring tools has been realized according to the initial design.
- The performance test results of the precision tapered workpiece measuring instrument can be seen in the following technical specifications of the equipment:
  - The size of the measuring instrument are 350 x 250 x 175 mm (for L x W x H). Measuring instrument weight = 12 kg.
  - The length of cylindrical workpiece measuring capability = 240 mm.
  - Taper angle measurement capability = max, 4° (tolerance $\pm 5''$).

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